Optoelectronic Packaging with Embedded Window

Field of the Invention

[0001] The present invention relates to the packaging of optical semiconductor or optoelectronic devices.

Background of the Invention

[0002] Optical semiconductors are key components in a wide variety of electronic devices. Because optical semiconductors are fragile and subject to damage by impact, abrasion, contaminants, moisture, heat, and other factors, each optical semiconductor is typically encased in a protective package. However, unlike the protective packages used to encase most other electronic components, the package for an optical semiconductor must incorporate a region that is transparent to light.

[0003] It has been a common practice to create an optoelectronic sensor package by mounting a sensor within a ceramic container with embedded conductive leads, then sealing the container with a window made of optical glass. The window does not directly contact the sensor, instead leaving some air space between the window and the sensor.

[0004] While this method can produce a relatively rugged sensor package with good optical properties, the enclosed space between the window and the die may contain moisture that can condense within the package. The enclosed space also adds at least two boundary layers to the light path, possibly resulting in unwanted reflection, refraction, or dispersion of light. These undesirable effects may be intensified if the plate is not parallel to the die surface.

[0005] Therefore, the requirements for extremely clean manufacturing conditions, humidity control within the container, and precise sensor die positioning with respect to the window often result in a packaged sensor that is bulky and expensive, sometimes accounting for half the total cost of a finished product.

[0006] Recent improvements in adhesives and manufacturing technology have made possible the simultaneous fabrication of large numbers of identical sensor packages in which the window is bonded directly to the die, thereby eliminating enclosed air space. This is accomplished by bonding a single sheet of suitable window material to an array of optical semiconductors, then cutting the sheet to separate the individual packages. Low-cost plastic encapsulation material may be used to seal the portions of the die that remain exposed.

[0007] While this method mitigates many of the problems arising from inclusion of an air space between a window and a die, the resulting package may retain a considerable amount of unusable window material, which, being heavy and expensive relatively to plastic encapsulation materials typically used to complete the package, adds unwanted weight and cost to the finished product. Further, every window produced in a given production run is essentially the same, limiting the manufacturer's ability to adapt to market demands by economically producing small numbers of sensor packages with windows having different characteristics.

[0008] What is needed, then, is a method for manufacturing a packaged optoelectronic sensor that reduces the bulk and cost of the packaged sensor while providing adequate protection for the die and mitigating the problems arising from space between the window and die. Windows should be placed and bonded individually, allowing flexibility in the manufacturing process. The method should utilize standard manufacturing equipment and raw materials.

Summary of the Invention

[0009] The present invention is a manufacturing method that utilizes standard manufacturing equipment and raw materials to produce compact, low-cost packaged optoelectronic components such as Erasable Programmable Read Only Memory (EPROM) chips, Electrically Erasable Programmable Read Only Memory (EEPROM) chips, Charge-Coupled Device (CCD) chips, Complementary Metal Oxide Semiconductor (CMOS) chips, and other optical semiconductor devices that are known in the art.

[0010] In a preferred embodiment of the present invention an aperture member is created from optical glass, plastic, or other materials that are transparent to the radiation spectra of interest. The material may be selected to absorb or pass specific radiation frequencies. An aperture member is typically cut from a plate of suitable material by a sawing, dicing, or scribing process, although other known processes may be used. The aperture member may be shaped, scored, or otherwise modified to refract, diffract, or diffuse light passing through. The aperture member may be sized and shaped to cover any portion of a semiconductor die, but is preferably sized to cover only the optically-sensitive portion of the die. Since the aperture member is individually manufactured, it may be of any suitable thickness and may have a horizontal cross-section of any suitable shape.

[0011] A semiconductor die with an optically-sensitive portion is then mounted on a lead frame. A computer-controlled pick-and-place machine selects an aperture member with desired characteristics. Pick-and-place machines are standard semiconductor manufacturing devices and may be programmed to select and precisely place a different component from one operation to the next. A transparent adhesive is applied to the aperture member, or to the die, or to both, then the pick-and-place machine positions the aperture member over the optically-sensitive portion of the die. The aperture member is pressed against the die, allowing the transparent adhesive to bond the aperture member to the die. The transparent adhesive may be an epoxy, silicon, tape, or other adhesive

materials that are known in the art.

[0012] Since the aperture member is attached directly to the die, no intervening air space remains to produce condensation or unwanted reflection, refraction, or diffusion. Since the aperture member is pre-sized and pre-shaped to cover the optically-sensitive portion of the die, the surfaces of the aperture member are automatically made parallel to the die surface upon installation and require no further cutting. Both the aperture member material and the transparent adhesive may be selected for desired refractive index, absorption, or other physical characteristics. The assembly is encapsulated with an epoxy molding compound or other encapsulate as is known in the art, leaving the leads and the upper portion of the aperture member exposed.

[0013] In an alternate embodiment of the present invention, a semiconductor die with an optically-sensitive area may be mounted with an adhesive material on a Printed Circuit Board (PCB) or ceramic substrate. The adhesive material may be a silver-filled epoxy, a polyimide epoxy, a thermally-conductive epoxy, a thermally or electrically non-conductive epoxy, an adhesive tape, or a metal alloy.

[0014] Metal wires such as gold, aluminum, or copper are bonded between the semiconductor die and the active circuitry on the substrate. A transparent adhesive is applied to the semiconductor die or to an aperture member made of borosilicate glass or another suitable material known in the art. The aperture member is placed on the optically-sensitive portion of the die by a pick-and-place machine. The assembly is baked. The die, aperture member, and substrate are encapsulated with an epoxy molding compound. Finally, the individual die package is separated from any attached frame or substrate and visually inspected.

Description of the Drawings

[0015] FIG. 1 shows a perspective view of an encapsulated optoelectronic device.

[0016] FIG. 2 shows a cutaway view of the encapsulated optoelectronic device of FIG. 1, revealing portions of a lead frame, semiconductor die, and embedded aperture member.

[0017] FIG. 3 is a cross-sectional view of the encapsulated optoelectronic device of FIG. 1.

[0018] Figures 4A through 4E are cross-sectional views showing the assembly of a Through Hole Device (THD) package.

[0019] Figures 5A through 5E are cross-sectional views showing the assembly of a Surface Mount Device (SMD) package.

[0020] Figures 6A through 6E are cross-sectional views showing the assembly of a Plastic Non-Leaded package.

[0021] Figures 7A through 7E are cross-sectional views showing the assembly of a package with a substrate, such as a Land Grid Array (LGA) or a Ball Grid Array (BGA) package.

Detailed Description of the Invention

[0022] Figures 1, 2, and 3 show different views of an embodiment of the present invention. FIG. 1 shows a perspective view of an encapsulated optoelectronic device. FIG. 2 shows a cutaway view of the same device, revealing portions of a lead frame, semiconductor die, and embedded aperture member. FIG. 3 is a cross-sectional view of

the same device. In FIG. 3, an optical semiconductor die **32** is secured upon a die paddle **30** with an adhesive epoxy material **31** or other bonding agent known in the art. Metal wires **36** are bonded from semiconductor die **32** to external metal leads **37**, which connect the circuitry of the semiconductor die **32** to external circuitry (not shown).

[0023] A transparent adhesive **34** is then applied to the optically active upper surface **33** of the semiconductor die **32**. An aperture member **35** made of borosilicate glass or other suitable material known in the art is placed by a pick-and-place machine on the upper surface of transparent adhesive **34**, affixing the aperture member **35** to the transparent adhesive **34** and the optically active upper surface **33** of the semiconductor die **32**, forming a transparent aperture above the optically active upper surface **33**. The pick-and-place machine may according to its programming instructions select an aperture member with any desired characteristics. Since in accordance with the method of the present invention each aperture member is individually placed and affixed to a semiconductor die, the pick-and-place machine may select a different type of aperture member for each of any number of sequentially-assembled optoelectronic packages.

[0024] An aperture member may be created from optical glass, plastic, or other materials that are transparent to the radiation spectra of interest. The material may be selected to absorb or pass specific radiation frequencies. An aperture member is usually cut from a plate of suitable material by a sawing, dicing, or scribing process, although other known processes may be used. The aperture member may be shaped, scored, or otherwise modified to refract, diffract, or diffuse light passing through. The aperture member may be sized and shaped to cover any portion of a semiconductor die, but is preferably sized to cover only the optically-sensitive portion of the die. Since the aperture member is individually manufactured, it may be of any suitable thickness and may have a horizontal cross-section of any suitable shape.

[0025] No open space is left between the semiconductor die **32** and the aperture member **35** after the two parts are bonded. An epoxy molding compound or other encapsulate as is known in the art is formed around the die paddle **30**, semiconductor die

32, and aperture member **35**, leaving the upper surface of the aperture member **35** and the external metal leads **37** exposed.

[0026] In an alternate embodiment of the present invention, the transparent adhesive **34** may be applied to a lower surface **39** of the aperture member **35**, with the lower surface **39** of the aperture member **35** then being positioned by a pick-and-place machine against the optically active upper surface **33** of the semiconductor die **32**.

[0027] In still another embodiment of the present invention the order of assembly steps may be varied. A transparent adhesive **34** is applied to the optically active upper surface **33** of the semiconductor die **32**. An aperture member **35** made of borosilicate glass or another suitable material as is known in the art is placed by a pick-and-place machine on the optically active upper surface **33** of the semiconductor die **32** and affixed to the transparent adhesive **34**, forming a transparent aperture above the optically active upper surface **33**. No open space is left between the semiconductor die **32** and the aperture member **35** after the two parts are bonded.

[0028] An optical semiconductor die **32** is then secured upon a die paddle **30** with an adhesive epoxy material **31** or other bonding agent known in the art. Metal wires **36** are bonded from semiconductor die **32** to external metal leads **37**, which connect the circuitry of the semiconductor die **32** to external circuitry (not shown). An epoxy molding compound or other encapsulate as is known in the art is formed around the die paddle **30**, semiconductor die **32**, and aperture member **35**, leaving the upper surface of the aperture member **35** and the external metal leads **37** exposed.

[0029] Figures 4A through 4E show the assembly of a preferred embodiment of the present invention. FIG. 4A shows a cross-sectional view of a metal lead frame as is known in the art, with a die paddle **40** and metal leads **41**. The lead frame is configured to accommodate a desired semiconductor and related electrical circuitry.

[0030] FIG. 4B shows a semiconductor die **43** attached by an adhesive material **42** to

the upper surface of the die paddle **40**. The adhesive material **42** may be dispensed, stamped, laminated, or applied by other means known in the art atop the die paddle **40**. The adhesive material **42** can be a silver-filled epoxy, a polyimide epoxy, a thermally-conductive epoxy, a thermally or electrically nonconductive epoxy, an adhesive tape, or a metal alloy. The adhesive material **42** is heated and cured, thereby securing the semiconductor die **43** to the die paddle **40**.

[0031] In FIG. 4C, metal wires **44** are bonded between the semiconductor die circuitry (not shown) and the metal leads **41**, connecting the die circuitry to external circuitry (not shown). The metal wires **44** may comprise gold, aluminum, copper or other suitable materials as are known in the art. An aperture member **46** is attached upon an optically-sensitive area of the die with a transparent adhesive material **45**. The transparent adhesive material **45** may be dispensed, stamped, laminated, or applied by other means known in the art to either upper surface of the semiconductor die **43** or the lower surface of the aperture member **46**.

[0032] FIG. 4D shows a cross-sectional view of the present invention after the die paddle **40**, the semiconductor die **43**, and aperture member **46** are encapsulated with an epoxy molding compound as is known in the art, forming a package **47** while leaving the upper surface of the aperture member **46** and the metal leads **41** exposed.

[0033] FIG. 4E shows the exposed metal leads **41** formed at approximately a 90-degree angle with respect to the plane of the die paddle **41**, creating a device especially suited for application as a Through Hole Device (THD) such as a Plastic Dual-Inline Package (PDIP). Finally, the individual package is punched out or cut from any attached metal frame to become a finished package.

[0034] Figures 5A through 5E show the assembly of an embodiment similar to that shown in Figures 4A through 4E, except that in FIG. 5E the exposed parts of the metal leads **51** may be formed as a gull wing, a J-form, or a C-form as required by external circuitry, creating a device especially suited for use as a Surface Mount Device (SMD)

package such as a Plastic Leaded Chip Carrier (PLCC), a Small Outline Plastic (SOP), a Small Outline Integrated Circuit (SOIC), or a Plastic Quad Flat Pack (PQFP).

[0035] Figures 6A through 6E show the assembly of an embodiment especially suited to non-leaded surface mount applications such as a Plastic Non-Leaded package or a Quad Flat Pack Non-leaded (QFPN). FIG. 6A shows a cross-sectional view of a metal frame as is known in the art, with a die paddle **60** and metal contacts **61**. The frame is configured to accommodate a desired semiconductor and related electrical circuitry.

[0036] FIG. 6B shows a semiconductor die **63** attached by an adhesive material **62** to the upper surface of the die paddle **60**. The adhesive material **62** may be dispensed, stamped, laminated, or applied by other means known in the art atop the die paddle **60**. The adhesive material **62** can be a silver-filled epoxy, a polyimide epoxy, a thermally-conductive epoxy, a thermally or electrically nonconductive epoxy, an adhesive tape, or a metal alloy. The adhesive material **62** is heated and cured, thereby securing the semiconductor die **63** to the die paddle **60**.

[0037] In FIG. 6C, metal wires **64** are bonded between the semiconductor die circuitry (not shown) and the metal contacts **61**, connecting the die circuitry to external circuitry (not shown). The metal wires **64** may comprise gold, aluminum, copper or other suitable materials as are known in the art. An aperture member **66** is attached upon an optically-sensitive area of the die with a transparent adhesive material **65**. The transparent adhesive material **65** may be dispensed, stamped, laminated, or applied by other means known in the art to either upper surface of the semiconductor die **63** or the lower surface of the aperture member **66**.

[0038] FIG. 6D shows a cross-sectional view of the present invention after the semiconductor die **63**, the aperture member **66**, and the upper portions of the die paddle **60** are encapsulated with an epoxy molding compound as is known in the art, forming a package **67** while leaving the upper surface of the aperture member **66** and lower surfaces of the metal contacts **61** exposed. Finally, as shown in FIG. 6E, the individual package is

punched out or cut from any attached frame to become a finished package.

[0039] Figures 7A through 7E show the assembly of an embodiment especially suited for Ball Grid Array (BGA) or Land Grid Array (LGA) packages. As shown in FIG. 7A, a Printed Circuit Board (PCB) substrate **71** comprising rubber, bismallimide triazene (BT), a ceramic, or other suitable material as is known in the art is configured to accommodate a desired semiconductor and related electrical circuitry.

[0040] FIG. 7B shows a semiconductor die **73** attached by an adhesive material **72** to the upper surface of the substrate **71**. The adhesive material **72** may be dispensed, stamped, laminated, or applied by other means known in the art atop the substrate **71**. The adhesive material **72** can be a silver-filled epoxy, a polyimide epoxy, a thermally-conductive epoxy, a thermally or electrically nonconductive epoxy, an adhesive tape, or a metal alloy. The adhesive material **72** is heated and cured, thereby securing the semiconductor die **73** to the substrate **71**.

[0041] In FIG. 7C, metal wires **74** are bonded between the PCB circuitry **79** and the semiconductor die circuitry (not shown). The metal wires **74** may comprise gold, aluminum, copper or other suitable materials as are known in the art. An aperture member **76** is attached upon an optically-sensitive area of the die with a transparent adhesive material **75**. The transparent adhesive material **75** may be dispensed, stamped, laminated, or applied by other means known in the art to either upper surface of the semiconductor die **73** or the lower surface of the aperture member **76**.

[0042] FIG. 7D shows a cross-sectional view of the present invention after the semiconductor die **73**, the aperture member **76**, and the upper portions of the substrate **71** are encapsulated with an epoxy molding compound as is known in the art, forming a package **77** while leaving the upper surface of the aperture member **76** and lower surfaces of the substrate **71** exposed.

[0043] Finally, FIG. 7E shows attachment of solder balls **78** to terminals on the lower

side of the substrate **71** for a BGA package. The solder balls **78** are not required on an LGA package. Finally, the individual package is punched out or cut from any attached substrate to become a finished package.

[0044] The embodiments described above utilize pre-cut aperture members rather than wafer-sized sheets, eliminating extra cutting steps and allowing increased flexibility in selecting the size, position, and optical characteristics of each embedded window.

[0045] The principles, embodiments, and modes of operation of the present invention have been set forth in the foregoing specification. The embodiments disclosed herein should be interpreted as illustrating the present invention and not as restricting it. For example, it should be recognized that a lead frame might be replaced with a printed circuit board (PCB) or a wired circuit board (WCB), and that an optoelectronic sensor might be replaced by a light-emitting semiconductor. Additionally, the assembly steps may be varied from the orders described, and in each case prior to assembly the transparent adhesive may be applied first to the aperture member or to both the die and the aperture member. In any embodiment of the present invention a pick-and-place machine may select a different type of aperture member for each of any number of sequentially-assembled optoelectronic packages.

[0046] The foregoing disclosure is not intended to limit the range of equivalent structure available to a person of ordinary skill in the art in any way, but rather to expand the range of equivalent structures in ways not previously contemplated. Numerous variations and changes can be made to the foregoing illustrative embodiments without departing from the scope and spirit of the present invention.